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**DIVINING DISASTER:
USING REMOTE SENSING TO PREDICT REGIONAL
INSTABILITY IN AFRICAN PASTORAL SOCIETIES**

by

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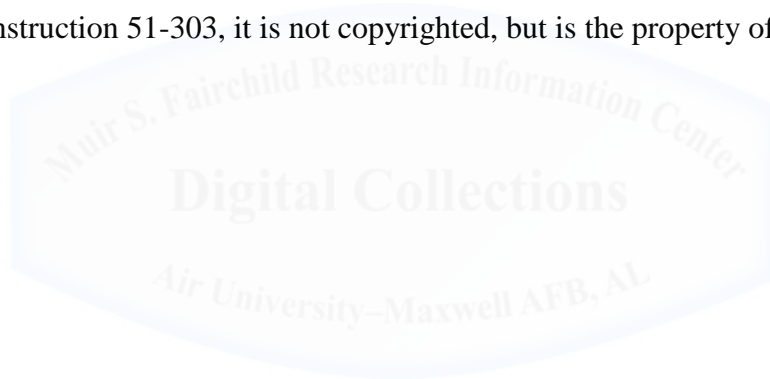
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Preface

This paper is an attempt to merge two outwardly dissimilar disciplines into a common effort to help AFRICOM predict, prepare for, and potentially avert humanitarian crises and the resulting regional instability deriving from natural and human induced rangeland failures. I have spent a career with the US Forest Service managing arid and semi-arid rangelands of the American southwest, combating many of the same factors that lead to the collapse of grazing lands in Africa. There are two distinct differences between these scenarios, however. The first is the ingrained cultural, economic, and social values associated with pastoralism, practiced by tens of million people on African rangelands. The second is the widespread instability that results when those rangelands fail, quickly exceeding the capacities of weak government institutions and outside organizations to provide humanitarian relief. Though the factors leading to rangeland failure are in many cases unavoidable, they are becoming increasingly predictable. Armed with such foresight, AFRICOM has the capability to work with governments in threatened regions, increasing their ability to prepare for and manage the effects of rangeland failures before they occur, potentially averting humanitarian crises and regional instability.

Abstract

US Africa Command's (AFRICOM's) mandate and organization are designed to improve the capacity of partner nations to promote regional stability. In the pastoral regions of Africa, rangeland failure stemming from drought, climate change, desertification, and anthropogenic changes is an underlying initiator of regional instability. AFRICOM can improve its capability to predict when, where, and how severely rangeland failure is likely occur. This will increase AFRICOM's ability to improve partner nations' and organizations' capacities to prepare for and manages these crises. Remote sensing of the rangeland failure indicators coupled with predictive modeling can fill some of the information gaps, leaving AFRICOM better prepared to proactively address regional instability.

This paper employs a problem/solution framework to evaluate remote sensing technology and predictive analysis models that relate to rangeland failure on the African continent. The goal is to improve AFRICOM's capability to proactively respond to impending humanitarian crises and regional instability sparked by the societal impact of rangeland failure in pastoral cultures.

Section 1: Introduction

The continent of Africa is roughly 3.5 times the size of the continental United States and has a population of approximately one billion people. Of those, two-thirds rely on non-arable lands for their livelihoods, regional economies, and cultural centers. With such a vast land area, some portion of the continent is always experiencing a drought or other natural disaster resulting in rangeland failure. While these events are natural and regular occurrences, they nevertheless result in significant social and humanitarian crises, which in turn often lead to regional instability. A quick response to such humanitarian crises has a stabilizing effect, but too often the international response is too little and too late to avert compounding negative effects. Therefore, it seems reasonable that early identification of looming environmental crises can speed the response, averting humanitarian crisis and any resultant social upheavals.

A significant aspect of the US Africa Command (AFRICOM) mandate is to promote stability in Africa. That often means working with partner nations, agencies and non-governmental organizations (NGO's) to facilitate the US response to crises on the continent. In this role, AFRICOM monitors on-going natural and man-made disasters to maintain situational awareness and aid relief efforts as appropriate. This is generally a reactionary posture, resulting in a delayed response. A more proactive posture would include greater use of predictive analysis regarding the natural forces that precipitate humanitarian crises. While predictive analysis tools are extensively used to forecast military and political trends and activities, such tools are rarely used to foresee impending natural disasters.

Numerous tools are available to support predictive analysis for such a purpose, the most efficient being remote sensing technology from space-based assets. Multi-spectral satellites and

modeling systems are currently being used by other organizations around the world, and the data is readily available. These systems are generally used by national weather services, scientists researching global climate change, economists forecasting crop yields, and occasionally humanitarian aid organizations. The data available are good, the models are improving, and the technology is proven. If AFRICOM were to take advantage of this information, they might be able to develop potential response options to predict impending natural disasters before they occur.

Framework

This paper will employ a problem/solution framework to evaluate remote sensing technology and predictive analysis models that relate to rangeland failure on the African continent. The goal is to improve AFRICOM's capability to proactively respond to impending humanitarian crises and regional instability sparked by the societal impact of rangeland failure in pastoral cultures. The paper will begin by examining AFRICOM's applicable mandates, the relationship between rangeland failure and regional instability. The paper will then describe the primary factors which drive African rangeland failure. An examination of pertinent remote sensing applications and predictive analysis tools will be made to assess their applicability to AFRICOM's mission. Recommendations will be offered with regard to data sources and models that might best be adopted to improve AFRICOM's posture in relation to drought-related humanitarian crises.

AFRICOM's mandates relevant to humanitarian and regional crises

One of the unique aspects of AFRICOM is its charter, which places great emphasis on a preventative security approach. It relies less on kinetic capabilities than on reducing the underlying sources of instability, extremism, and conflict in Africa.¹ This fact is embodied in its

organizational structure which has two co-equal deputy commanders - a Vice Admiral in charge of military operations, and an Ambassador-rank civilian leading civil-military activities, who directs the command's plans and programs associated with health, humanitarian assistance and de-mining action, disaster response, security sector reform, and Peace Support Operations.² In his 2011 Commander's Intent message, General Ward (Commander, US Africa Command) stressed AFRICOM's commitment to integrating, "U.S. government, diplomacy, development, defense and intelligence efforts... in the areas of conflict prevention and crisis response". He went on to emphasize, "[W]e will support and facilitate regional responses to security, humanitarian, and disaster relief contingencies."³ To this end, AFRICOM has established a Disaster Planning and Preparedness Program which is focused upon how the command can support the US response to natural, man made, and humanitarian disasters in Africa. When visiting with African partner nations about their military concerns, one of the recurring themes that AFRICOM hears is less of a fear about conventional state to state conflict, but rather the cross-border regional instability, mass migrations, and societal impacts originating from natural disasters. In the pastoral regions of Africa, rangeland failure stemming from drought, climate change, desertification, and anthropogenic changes is a prime initiator of regional instability. A greater ability for AFRICOM to predict when, where, and how severely rangeland failure is likely occur, will increase its ability to improve partner nations' and organizations' capacity to prepare for and manages these crises.

Section 2: African Rangelands & Pastoralism

Covering approximately 70 percent of the world's land area (outside of Antarctica)⁴, rangelands are vast natural landscapes in the form of grasslands, shrublands, woodlands, wetlands and deserts. In Africa, it is perhaps easier to define rangelands by clearly describing what they are not. Rangelands are not: barren desert with active dunes, farmland, closed canopy forests, or land covered by solid rock, pavement, or glaciers. They include vegetation types such as desert grasslands and shrublands, woodlands, savannas, and thorn scrub. Outside of the tropical rainforests of central Africa, the heart of the great Sahara Desert, and scattered farmlands and urbanized areas, the remaining 68 percent of the continent is rangeland. Rangelands are distinguished from pasturelands because they grow primarily native vegetation, rather than plants established by humans. Due to highly variable precipitation patterns, most African rangelands are unable to support crop agriculture although speculative cropping is not uncommon in many regions.

African rangeland ecosystems are capable of supplying a wide diversity of products including forage for domestic and wild herbivores, water which feeds several of the world's largest river systems, and habitat for vast numbers of wildlife species, often creating significant ecotourism opportunities. In Tanzania and Kenya for example, tourism drawn largely by the great wildlife herds of the Serengeti rangelands is the second largest contributor to the national gross domestic product (GDP) behind agriculture. With global attention focusing on combating global climate change, scientists determined that expansive rangelands such as those in Africa are second only to tropical rainforests in their capacity to extract and retain carbon from the

atmosphere, thereby reducing atmospheric greenhouse gasses. This paper will focus on the use of rangelands for livestock production and the pastoral societies who do so.

What is Pastoralism?

*"Pastoralism is the finely-honed symbiotic relationship between local ecology, domesticated livestock and people in resource-scarce, climatically marginal and highly variable conditions. It represents a complex form of natural resource management, involving a continuous ecological balance between pastures, livestock and people."*⁵

Pastoralist people derive the majority of their household food, income and way of life on mobile livestock herding.⁶ They live in a range of environments in many countries across every continent in the world. In sub-Saharan Africa, mobile pastoralism occurs predominantly in arid and semi-arid rangelands. These areas tend to be hot and dry, with low and erratic rainfall. Few livelihoods are suited to this arid environment but mobile livestock husbandry is particularly well adapted.

It is generally theorized that pastoralism in Africa evolved in response to climate variability over 6000 years ago when the Sahara entered a period of prolonged drying. With no reliable supplies of permanent water, pastoralism enabled people to adapt to an increasingly arid and unpredictable environment by moving livestock according to the shifting availability of water and pasture.⁷ This opportunistic management system continues to this day, making pastoralism an effective and efficient land use and production system for the dry rangelands of Africa.

Africa's rangelands have co-evolved with grazing and browsing herbivores. In many regions, domestic livestock and wild grazers are an integral part of the natural environment, which depends on herbivores to maintain its ecological balance. By grazing and trampling the

pasture, livestock can improve pasture health, transport seeds, and embed seeds into the earth. At the same time, they provide manure for nutrient cycling. Provided the livestock are managed effectively, and seasonal movements remain possible, grasslands can thrive under pastoralist care.

The dry and pastoral lands of East Africa occupy over 70 percent of the Horn of Africa. This ranges from 95 percent of the total land area in Somalia and Djibouti, to more than 80 percent in Kenya, 60 percent in Uganda, and between 30 to 60 percent in Tanzania.⁸ Kenya and Tanzania both have over four million pastoralists, constituting over 10 percent of their populations. In Uganda, pastoralists make up 22 percent of the population, around 5.3 million people. Pastoralists constitute an estimated 16 percent of the population of the Sahelian Zone of Africa, but in a few countries such as Somalia and Mauritania, they are the majority of people.⁹ As one of the more effective livelihood system in these drylands, pastoralism is vital to the stability of Africa and to the well-being of millions of people who live there.¹⁰

Regional political institutions often marginalize pastoralist societies due to their nomadic nature, which is at odds with many government programs designed to encourage more sedentary agricultural practices. Additionally, pastoralists are often from ethnic or political minorities. As a result, in many African regions pastoralists are finding themselves in untenable and unrepresented positions, which foment civil unrest often focused at local authorities, rival clans, or government institutions.

Over the past four decades, pastoralist grazing lands and water resources receive greater pressure as populations increase, and grazing land are taken for cultivation, conservation areas, and state use. In Tanzania for example, the creation of multiple conservation areas has made

more land unavailable to pastoralists than all other factors put together. As a result, pastoral livestock have moved onto lands that are too small to be sustainable for pastoral production as pastoralists rely on freedom of movement to be able to manage the rangelands effectively.¹¹ In East Africa, the livestock population has seen little growth because of disease epidemics and starvation associated with floods and recurrent drought. The human population is growing, however. The result is more pastoralists reliant on fewer livestock per capita.

Such external pressures have contributed to pasture shortages, land degradation, and socio-economic disintegration. Although many pastoralists are adapting by diversifying into crop cultivation, sending relatives off for urban wages, or engaging in commerce and trade, many continue to manage their livestock in the old way. In many areas where there is a shortage of pasture, traditional systems of management are contributing to the problem of land degradation.¹²

Frequent droughts compound these challenges by greatly diminishing forage and water availability. Increased demands on the rangeland resources, population dynamics, government policies, ethnic and political marginalization, cultural and tribal rivalries, poor land management practices, and drought induced resource scarcity too often lead to the failure of African rangeland to support their pastoral populations. This in turn has repeatedly led to regional instability.

Instability Induced by Rangeland Failure

The failure of African rangelands to meet the needs of their dependant pastoral societies has repeatedly led to instability in several African regions. Pastoral groups increasingly shift away from the areas that are no longer viable, into zones that are less dry, with more predictable rainfall patterns. Human migration induced by demographic pressure and environmental

stressors, often leads to conflict between traditional groups and those with statutory land tenure status, and fuels tensions among multiple resource users.¹³ It also often brings new and sometimes inappropriate land management technologies and methods that exacerbate an already volatile situation.

The loss of rangeland productivity has led to direct conflict between pastoral tribes competing for the same limited forage or water, conflicts between grazers and farmers when herds move into agricultural lands, or revolts against government interest when unauthorized herds move into conservation areas. However, the greatest instability is not caused by the direct confrontations, but rather by large movements of displaced and vulnerable people, generally across national boundaries of nations with little ability to provide relief to large-scale humanitarian crises. Numerous examples of how resource competition significantly increases the risk of conflict between different user groups follows. Specifically, regional instability caused by mass migrations and conflicts between pastoralists and other grazers, farmers, government institutions will be examined.

Grazers vs Grazers

When rangeland productivity collapses or life-giving water is scarce, the few remaining sources become hotly contested. For a pastoral people whose livelihoods and status are based upon maintaining livestock herds, the loss of large numbers of animals is socially and economically devastating. Such stresses have led to internecine conflicts in many regions of Africa. An example comes from the border regions of Uganda, Kenya, and Ethiopia known as the Karamoja Cluster. In this region, a tradition of raiding has developed in response to competition for scarce resources, particularly water and pasture, and the cultural value placed on cattle. In 2004, violent pastoral conflict in the Karamoja Cluster alone resulted in more than 600

human deaths and the loss of over 40,000 heads of livestock (primarily cattle and goats) in just 12 months.¹⁴ Livestock raiding is often followed by vigilante retribution, spilling into outright clan warfare. In some instances, local law enforcement agencies were goaded into crossing national boundaries to pursue offenders, resulting in semi-official cross border incursions, which greatly raised national tensions in the region. In an effort to preempt or contain the very real possibility of similar violence in the future, the Conflict Early Warning and Response Mechanism (CEWARN) was established by Ethiopia, Uganda, Kenya, Somalia, Eritrea, and Djibouti.¹⁵ CEWARN's purpose is to monitor potential trouble spots and prepare affected governments for a rapid response before tensions create unmanageable situations. Rangeland failures in the pastoral zones are one of CEWARN's primary indicators for likely widespread unrest, instability and violence.

Pastoralists vs Farmers

The search for available pasture for livestock herds is increasingly leading to conflicts between pastoralists and farmers. When herds move into farmers' fields, they can have devastating impacts on the anticipated harvest by eating or trampling the crops. In regions where a large percentage of agriculture is purely for subsistence, the loss of crops has more than just an economic impact - the survival of a family or village can be at stake. Under such circumstances, it is not unexpected that violence can rapidly escalate between two desperate groups. Well-documented case studies of such conflicts are found in most regions of Africa, although Nigeria and Sudan present the more large-scale examples.

Sudan is Africa's largest nation in size and fifth most populous. Despite the recent increase in oil contributions, agriculture drives the Sudanese economy, and employs 80 percent of the population. Plagued by a history of conflict, government corruption and poor

infrastructure, drought has repeatedly been the catalyst for widespread violence.¹⁶ Though the mainstream media has generally depicted much of the internal strife in Sudan as conflict divided along religious and political lines, it was initiated on economic lines during periods of drought and resource scarcity when pastoralist moved their herds into cultivated lands in search of forage and water. Muslim Arab farmers were impacted just as much as African Christian farmers. Similarly, African Christian herders were just as intrusive and violent as African Muslim herders. The conflict rapidly devolved as political motivations exploited and intensified the unrest which ultimately resulted in the humanitarian crisis in the Darfur and neighboring regions.

Similar conflicts between herders and farmers are occurring in Nigeria. Rangeland failure due to desertification, climate change and short-term drought is threatening the livelihoods of over 15 million pastoralists in northern Nigeria. In 11 of Nigeria's northern states, 35 percent of land that was arable 50 years has transformed to desert. In other states, the rainy season has dropped from 150 days to 120 days in the past 30 years, reducing vegetative production by 20 percent.¹⁷ Increasingly, resource scarcity is bringing pastoralist and farmers into competition and ultimately to conflict. In 2009, two days of fighting between user groups killed over 500 people. The Nigerian government has thus far been able to intercede to prevent greater escalations, but many analysts predict greater widespread conflict in times of environmental stress.

The examples of instability driven by environmental stress in Nigeria and Sudan focused on conflict internal to a country. There are also examples where rangeland failures and herder-farmer conflicts have threatened to instigate state on state confrontations. In 1989, tensions over grazing disputes and land tenure erupted into ethnic riots and a border war between Senegal and Mauritania, which lasted two years and displaced over 250,000 people.

Pastoralists vs Government Institutions

National and international policies that have set aside large tracts of rangelands for conservation or tourism to the exclusion of traditional pastoral uses have led to conflicts between governments and their pastoral societies during periods of resource scarcity. In the search for pasture or water, herders may trespass on national parks, leading to conflicts with those responsible for managing the reserves. Many pastoralists do not recognize the validity of national parks that were delineated out of traditional pastoral lands. Due to their marginalized status in many African countries, pastoralists were often not seen as contributing stakeholders in the formation or management of the reserves. In such cases, hostility and conflict has often erupted. In Namibia, tribes that embraced the formation of reserves have prospered from government and non-governmental organizations (NGO) economic incentives. Those that opposed the formation were relocated, and have been the heart of a low-grade resistance movement, which becomes increasingly active during periods of resource scarcity. They are also particularly active in cross-border poaching activities, which have significantly raised tensions between Namibia and its eastern neighbors, Botswana and South Africa. USAID and the US State Department assess that lingering land use and allocation issues have a profound potential to destabilize Namibia and South Africa, particularly during periods of drought.¹⁸

Where pastoralist needs and traditional uses are incorporated into the management of reserves, the stresses associated with drought periods have been somewhat lessened. Some Tanzanian reserves accommodate pastoral and aboriginal uses during dry periods. While this has not eliminated resentment about the reserves, it has reduced tensions and mitigated short-term instability.

Mass Migrations

The greatest destabilizing effect associated with rangeland failure and pastoral societies is the massive numbers of displaced persons that accompany these events. Across the continent, the loss of rangeland productivity has moved millions of people from their traditional territories. A 2009 study estimated there were at least 11.6 million internally displaced persons in 26 African countries - fully 40 percent of the world's total.¹⁹ Such movements result in staggering economic losses, severed social fabrics, and ethnic and religious strife. The human costs of these events have ripple effects far beyond the initial displacements and are seen in increased disease related mortality, malnutrition, lack of education, lost productivity, increased exploitation and violent crime. The strains upon fragile governments to provide relief for displaced persons can be crippling, and most African governments would be unsuccessful at these efforts without the assistance of international aid organizations. Refugee and relief camps are also notorious incubators for insurrection or terrorist movements.

Section 3: Factors Driving African Rangeland Failure and Tools to Monitor and Predict Them

The causes of rangeland failure in Africa are as diverse and complex as the continent itself, yet it is critical to identify those causes to predict future crises accurately. There are four broad classifications, which alone or in combination, lead to the majority of the observed decreases in rangeland productivity: Drought, Anthropogenic Change, Climate Change, and Desertification. The reality is that rarely are any of these driving factors acting independently. Rather, they tend to be expressed in concert, and the result is too often a drastic loss of rangeland productivity, along with the ensuing social and environmental costs. Each of these factors are discussed in detail, along with tools to monitor ongoing events and models to predict future occurrences.

Drought

Drought is a temporary departure from average rainfall conditions over a season or more, resulting in adverse impacts on vegetation, animals, and/or people. Drought differs from aridity, which is a permanent feature of climate in regions where low precipitation is the norm, as in a desert.²⁰ Drought can be short-term or last several years, such as the Sahel droughts of the 1970s and 1980s, which resulted in widespread famine, mass migrations, and the loss of over one million lives.

Drought is a normal, recurring feature of the climate in most parts of the world and has been a driver of human dynamics in Africa for millennia. In a pastoral context, extended periods of below average precipitation initially result in a reduction of vegetative growth - the forage base for livestock. This rapidly translates into decreased animal productivity in the form of

reduced weight gain, milk production, and reproduction. Depending upon the duration and severity of the drought, mortality of perennial grasses and shrubs will eventually occur, followed by livestock mortality if alternate forage sources are not available.²¹

A study conducted in the Pastoral Zone of Niger in 1980-1982 illustrated the variability experienced by pastoralists in drought prone regions of Africa. At the Gadabeji study site, forage production dropped from nearly 1200 kg/ha in 1980 to less than 200 kg/ha in 1981.²² To herders in this location in 1981, this represented only 16% of the forage resource available the previous year, and resulted in massive economic, social, and environmental impacts. Unfortunately, these kinds of fluctuations are relatively frequent across large swathes of the continent.

Causes of Drought

Due to Africa's large landmass, no single factor can explain the occurrence of droughts across the continent. However, causal factors are being identified for regional drought occurrences. Researchers at the National Oceanographic and Atmospheric Agency's (NOAA) Climate Diagnostics Center (CDC), and the National Center for Atmospheric Research (NCAR) investigated a series of droughts experienced in the Sahel and Southern Africa in the 1970's and 1980's. Examinations of the climate histories and recorded sea surface temperatures since 1950 have resulted in a striking correlation. Focused experiments and climatic models have revealed that a cooling of the water in the tropical region of the Atlantic Ocean just north of the equator relative to warming of the tropical South Atlantic are what drives Sahelian droughts. This differential resulted in the failure of the African monsoon to extend north into the Sahel. Not all droughts are created equally, however. The same series of investigations revealed that droughts

in Southern Africa, while also of ocean origins, are attributed to a progressive warming of the Indian Ocean.²³

Monitoring Drought Conditions

One of the challenges with monitoring weather conditions in African is the lack of infrastructure and weather observation sites in vast portions of the continent. The lack of direct observation stations makes the use of remote sensing even more valuable. However, the lack of observation sites also make it difficult to validate the accuracy of many of the predictive models, often resulting in a broader scale of accuracy than would generally be acceptable in more developed regions of the world. Numerous tools are available for monitoring current conditions and estimating anticipated weather conditions.

Normalized Difference Vegetation Index (NDVI) imagery provides an indication of the plant growth (vigor), vegetation cover, biomass production and density of vegetation, and are sometimes referred to as "greenness maps".²⁴ NDVI imagery is created from the red and near infrared reflectance observed by the Advanced Very High Resolution Radiometer (AVHRR) sensor on NOAA meteorological satellites. Processed by NASA and the U.S. Geological Survey, the pixilated data has an 8.0 x 8.0 km resolution. NDVI values range between -1 and +1, with dense vegetation having higher values (e.g., 0.4 - 0.7), and lightly vegetated regions having lower values (e.g., 0.1 - 0.2). The primary use of these images is to compare the current state of vegetation with previous periods, for example the same time in an average year or a reference year (a particularly good or bad year) to detect anomalous conditions, such as drought. One of the limitations of this tool is it only detects actively growing green plants, so grasses that are in a dormant stage will not be shown. These data are available on a continental, regional, national, and sub-national scale (Figure 1).²⁵

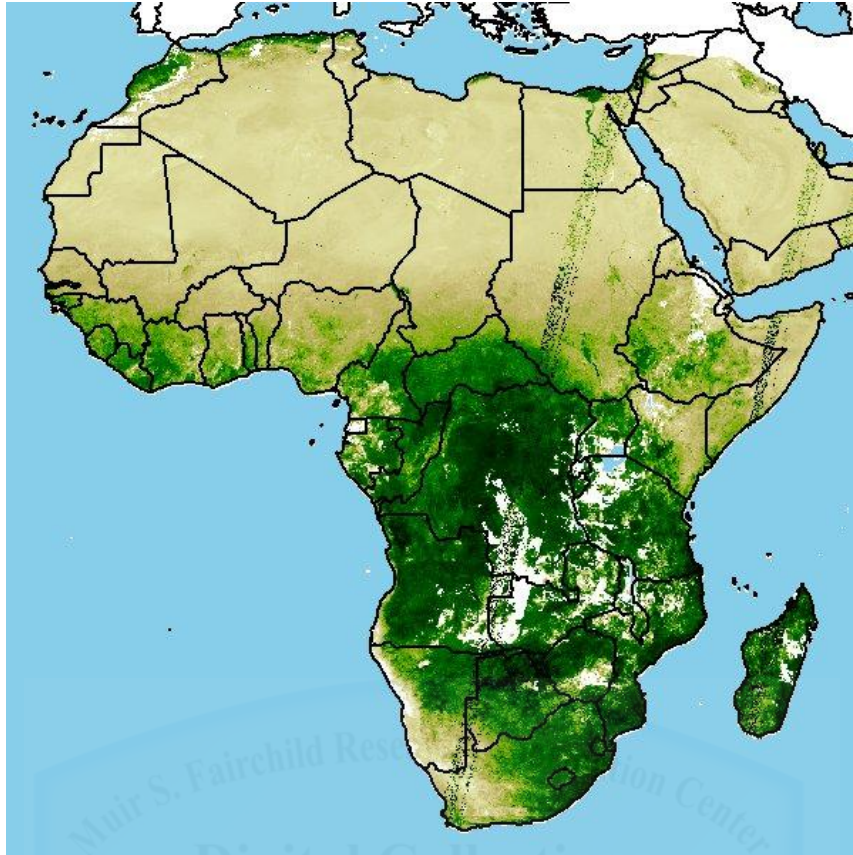


Figure 1. Normalized Difference Vegetation Index (NDVI) Imagery from January 2010 showing active vegetation growth in southern, central and western Africa, and minimal growth in more arid regions.²⁶

Rainfall Estimation (RFE) imagery is an automated product to provide climate information as well as inputs for hydrological and agro-meteorological models. Meteosat infrared data, rain gauge reports from the global telecommunications system, and microwave observations from sensors on board Defense Meteorological Satellite Program satellites are used to derive the information.²⁷ RFE models in Africa have a approximate resolution of 10 kilometers (Figure 2).

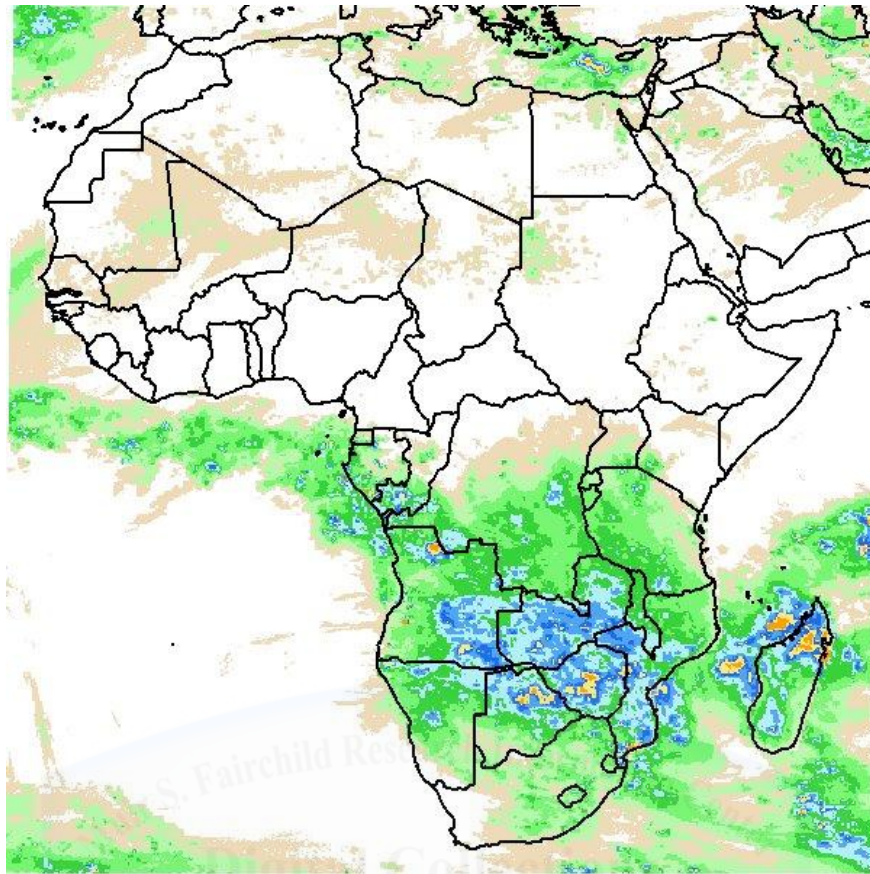


Figure 2. Rainfall Estimation imagery from January 2011, showing widespread precipitation events which lead to significant flooding in much of southern Africa.²⁸

The **Inter-Tropical Convergence Zone (ITCZ)** is one of the dominant climatic factors in Sub-Saharan Africa. Occurring where the trade winds of the northern and southern hemisphere come together, it is a belt of active convective activity, resulting in a perpetual series of rainstorms. In Africa, the ITCZ is drawn north in the summer by the heating of the Sahara, and south in the winter (astral summer). As a result, the ITCZ directs primary rainy seasons and associated growing seasons from Botswana in the south during December-February, transitioning through central Africa until it reaches its northern extent in the Sahel in July-September, before returning south again (Figure 3). Disruptions in either the northern or the southern extents of this flow tend to result in widespread droughts in those regions.²⁹ Tracking

the ITCZ regularly helps indicate how the current growing season will develop and is an early indication of seasonal rangeland failure, particularly in the northern and southern transitional zones.

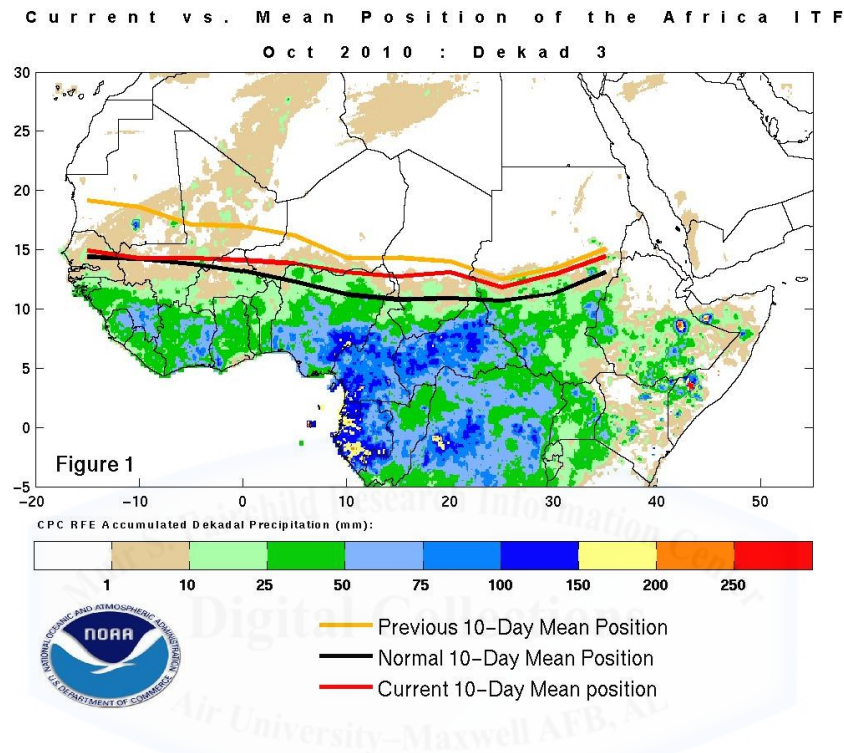


Figure 3. An example of tracking the northern edge of the Inter-tropic Convergence Zone (ITCZ) as it retreats south in October 2010.³⁰

The use of tools such as NDVI, RFE, ITCZ are extremely helpful for tracking the current season's rainfall production, but they do not provide more than a couple months warning of impending problems. Fortunately, models are available to provide earlier indications of drought and resulting rangeland failure.

Predicting Drought in Africa

As noted earlier, a strong correlation has been made between surface water temperatures in the Atlantic and Indian Oceans and the occurrence of droughts on the African continent. Several models are utilizing this correlation in combination with other influences to generate

regional projections several months in advance. The El Niño Southern Oscillation (ENSO) in the Pacific has global impacts. These include strong influences on the African Monsoon. When combined with the influences of Indian and Atlantic sea temperatures, a historical analysis of ENSO events correspond well to district wet or dry seasons in varying regions of Africa (Figure 4).³¹

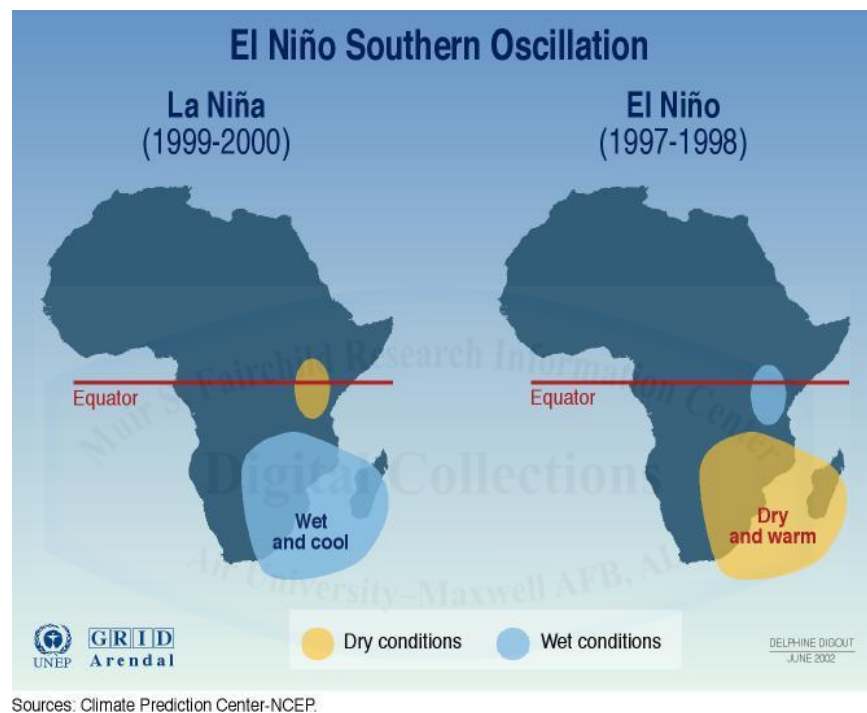


Figure 4. El Nino Southern Oscillation (ENSO) impact on Southern Africa.³²

One of the most promising models is the National Centers for Environmental Predictions' **Climate Forecast System Reanalysis (CFSR)**, which represents the interaction between the earth's oceans, land, sea ice, and atmosphere in a global, high-resolution system. The CFSR has the ability to make accurate climate projections from two weeks to over nine months into the future, with greater spatial and temporal resolution than any other model to date. Additionally, the CFSR generates updated forecasts multiple times per day, which are publicly available.³³

Climate Change

On a grander scale, climate change refers to changes in weather patterns or events over the period of decades or longer. Climate change is directly affecting the pastoral regions of Africa and current projections indicate that the future impacts will be far more significant. Many African rangelands are particularly susceptible to adverse climatic changes simply because they are already marginal. Analysis of the impacts of climate change suggests that agro-economic systems are the most vulnerable sectors, and that climatic effects will be exacerbated in the developing nations of Africa due to their heavy reliance on subsistence agriculture and lack developed industrial sectors for diversification.

The anticipated impacts of climate change will be considerable in tropical regions. Models indicate that overall crop yields may fall by 10 to 20 percent by 2050 because of warming and drying, but there are regions where agricultural production losses may be much more severe. Developing countries have greater vulnerabilities to the effects of climate change than more developed countries due to a lower adaptation capacity in the developing world. Of the developing countries, many in Africa are seen as being the most vulnerable to climate variability and change due to their high reliance on natural resources, limited ability to adapt financially and institutionally, low per capita GDP and high poverty, and a lack of safety nets.³⁴

Monitoring & Predictive Tools

The global implications of climate change have driven the development of numerous modeling tools to estimate the projected impacts. While there is variability between the models, most indicate that the vast majority of Africa will become warmer and drier due to global climate change. One of the quantifiable estimates from these projections is the percentage of growing

seasons that will fail. By the year 2050, models indicate that with the exception of limited coastal areas of West Africa, the entire continent can anticipate drastically increased incidence of crop and rangeland failure (Figure 5).³⁵ With global efforts attempting to identify the implications of climate change under numerous scenarios, the fidelity of these products will only increase with time.

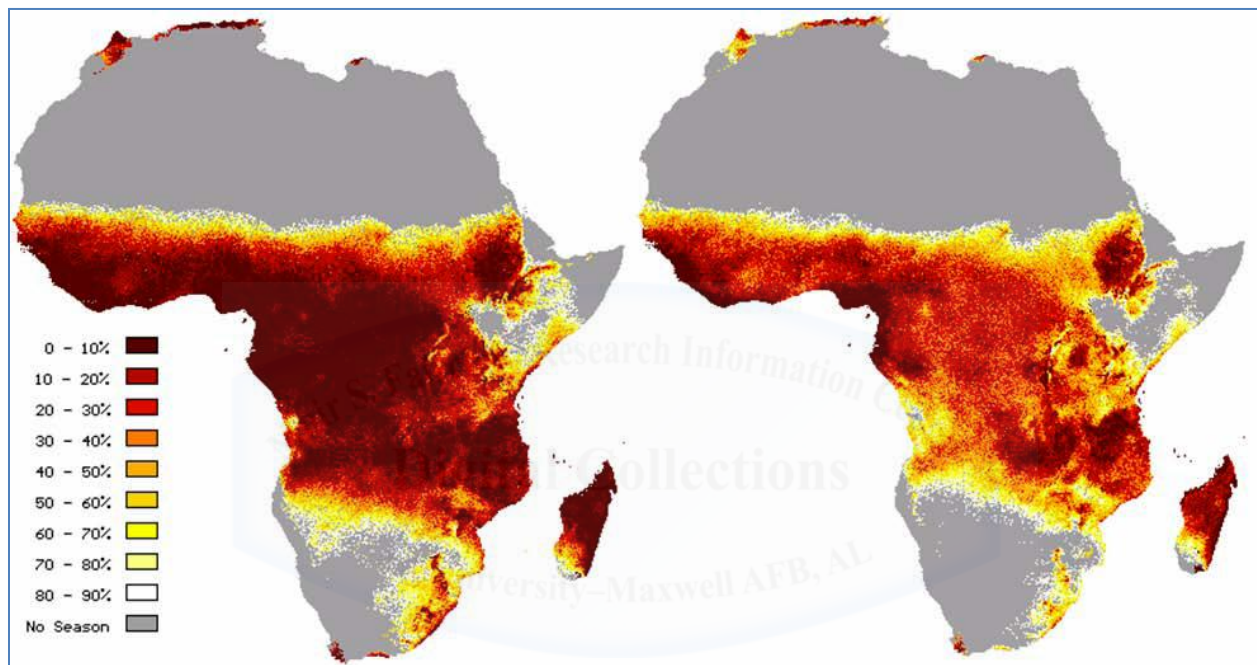


Figure 5. Percentage of failed growing seasons: left panel displays current conditions; right panel displays projected conditions in 2050.³⁶

One of the challenges of monitoring the effects of climate change on the vegetative communities of the African rangelands is an effect known as biological inertia. This occurs when vegetation established from seed under a prior climatic regime may survive in the present regime in a vegetative state. In this phenomenon, plants may persist for tens or hundreds of years in conditions very different from those under which they initially became established.³⁷ If plant communities today or in the near future are unable to successfully reestablish from seed

sufficiently to maintain the population, vegetative composition is destined to change dramatically and not recover from events such as short-term droughts, or overgrazing. Societies that depend on vegetative communities—established under prior, more favorable, climate conditions—are less likely to survive an apparent collapse of the rangeland resource.

Anthropogenic Change

Anthropogenic or human-induced changes are environmental changes, which occur as a direct result of human activities. In the context of African rangeland failures, there are several types of human actions, which directly degrade pastoral productivity. The most widespread is the occurrence of overgrazing by domestic livestock, followed by deforestation for fuel wood, attempting to farm marginal lands, and depletion of underground aquifers through over-pumping and poor water management.

Most developing countries have experienced destructive grazing practices to varying degrees. In many cases, range deterioration is greatest near watering points and other areas of livestock concentration. Large regions have experienced significant changes in the vegetative composition of the rangelands, where annual grass species that are less reliable as forage or ground cover, replace perennial species.³⁸

Unlike extremely fertile regions of the world such as river floodplains or the grain belts of the American Midwest or Eastern Europe, most arid regions have very shallow soils. The most productive portion of the soil horizon in these areas is the top one inch, commonly referred to as the A-horizon. This portion of the soil profile is critical for nutrient cycling, water absorption, and herbaceous production. It is also the most vulnerable portion of the soil to wind and water erosion after the vegetation has been removed. Once the A horizon is gone, the

productivity of a landscape is greatly diminished. In arid environments, it takes over 1,000 years to develop one inch of soil.³⁹

In pastoral societies, since the number of livestock directly relate to status (i.e., personal/tribal wealth and status), there is no immediate incentive to reduce livestock impacts on the landscape. Additionally, rapid population growth is exacerbating the demands for more livestock. In the past 35 years, the Sahel has experienced rapid growth in population. In 1961 the Sahel was home to approximately 19 million people, and by 2000 this had exploded to 50 million. While only a portion of this population growth directly relies on pastoral resources, the increased demands and resultant environmental impacts are greatly degrading the productivity of already marginal rangelands. The need to produce more food to meet the demands of an increasing population has led to overgrazing and conversion of rangelands to cultivated lands, even in areas that do not have adequate water and soil fertility. Unsustainable irrigation and cultivation practices in the semi-arid zones have resulted in severe soil salinization and erosion, which in turn leads to a reduction in food productivity and long-term food insecurity

Monitoring & Predictive Tools

Driven by international agreements designed to curb global deforestation and increase carbon sequestration, numerous tools are under development to monitor anthropogenic environmental changes. One effort is being led by the a computing facility developed by the Planetary Skin Institute (PSI), a not-for-profit organization set up by Cisco Systems and NASA. PSI has developed the Automated Land-change Evaluation, Reporting and Tracking System, (ALERTS), to merge numerous types of data to monitor where and how land use is changing. ALERTS provides global coverage, updated every six weeks, is publicly available, and will soon

be including predictive analysis algorithms⁴⁰. Google's Earth Engine will soon be offering complementary data and computing power for public analysis.⁴¹

Desertification

One of the other primary factors leading to African rangeland failures is desertification. The UN defines desertification as "land degradation in arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities⁴²." The Natural Resources Conservation Service (NRCS) (part of the US Department of Agriculture) identifies five primary causal factors of desertification from mismanagement:⁴³

1. Excessive and continuous soil erosion resulting from over and improper use of lands, especially marginal and sloping lands;
2. Nutrient depletion and/or soil acidification due to inadequate replenishment of nutrients or soil pollution from excessive use of organic and inorganic agri-chemicals;
3. Reduced water holding capacity of soils due to reduced volume of soil and reduced organic matter content, both a consequence of erosion and reduced infiltration due to crusting and compaction;
4. Salinization and water-logging from over-irrigation without adequate drainage; and
5. Unavailability of water stemming from decreased supply of aquifers and drainage bodies.

Whether caused by land mismanagement or climate change, desertification is leading to the loss of African rangeland productivity at an alarming rate. In the past 50 years the Sahara Desert has advanced south into the Sahel at a rate of two to five kilometers per year. During the past century, the fragile ecosystem of the Sahel region has been unable to sustain its vegetation. Livestock overgrazing, adoption of western farming practices, and poor water management

contributed to the Sahel region's desertification. When combined with seasonal droughts, the rate of desertification greatly accelerates.

Figure 6 shows the current desertification vulnerability of African regions based upon inherent physical attributes. Contrast this with Figure 7, which depicts the risk of human induced desertification in Africa, derived from the inherent desertification risk of a region, overlaid with its population density, and the predominant land management systems of that region. This correlates to over 20.3 percent of the African population - roughly 200,000,000 people - are at high or very high risk from lost productivity due to desertification. Moreover, an NRCS report states, "Desertification is rampant in much of the continent and will permanently destroy the agricultural production potential. Correcting the degradation effects will be more expensive and the low resilience characteristics of many of the soils suggest that high levels of productivity cannot be expected even after mitigation technologies are used. Under current systems, most of the countries will be unsustainable and if desertification is not controlled, their ability to attain sustainability will be significantly reduced."⁴⁴

Monitoring and Predictive Tools

Remote sensing technology has great applications for monitoring the occurrence of desertification across the continent. Satellite imagery in the visible spectrum has been utilized to monitor changes in the landscape for years. Hyper-spectral imagery has far greater application because it can accurately derive more quantitative and specific soil properties directly linked to soil degradation such as organic matter, soil chemical properties, infiltration capacity, aggregation capacity, and runoff coefficient.⁴⁵

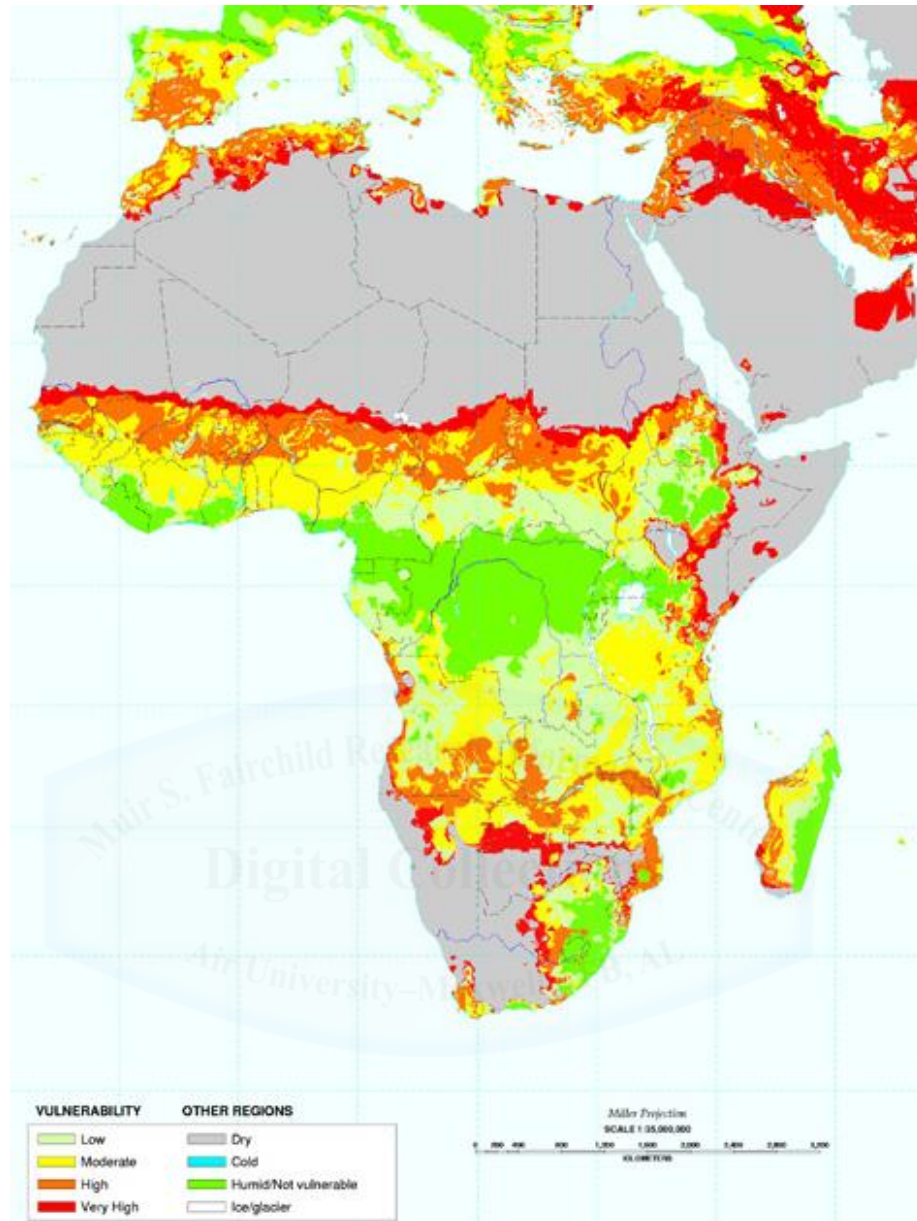


Figure 6. Inherent risk of desertification in Africa.⁴⁶

Risk of Human Induced Desertification

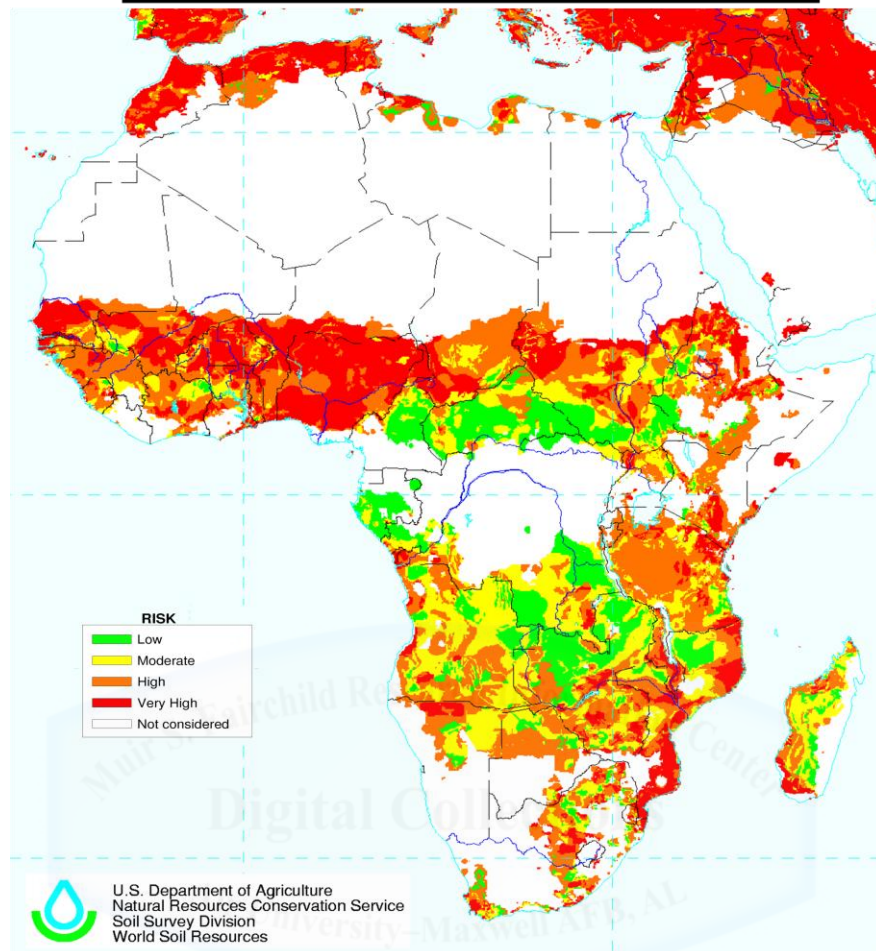


Figure 7. Risk of human induced desertification in Africa.⁴⁷

Of greater utility are models that predict where desertification will occur, to what extent, and at what rate. Several models are under evaluation, but a team of Spanish researchers developed one of particular interest. Their model evaluates desertification risk of multiple human-resource interactions and determines what combinations are sustainable versus others that result in long-term desertification.⁴⁸ Though this model and others similar to it are undergoing evaluation, they are expected to accurately estimate when and where desertification will occur in a landscape.

Section 4: Conclusion and Recommendations

Monitoring and forecasting African rangeland failures can serve AFRICOM as an indicator of pending regional instability. Indicators to follow are drought, climate change, anthropogenic changes, and desertification. Though this paper analyzed each of these indicators separately, it is critical to recognize that they rarely appear individually and the compounding effects are the true threat to the landscape and the resident societies. All of these conditions should be monitored using remote sensing, and predictive analysis should be utilized to identify likely areas of rangeland failure with the resulting potential for instability in African pastoral society.

While the Department of Defense has formidable remote sensing capabilities, these resources and their processing requirements are in high demand, and tasking continental coverage to monitor the indicators of rangeland failure may not compete favorably against other requirements. Fortunately, numerous civilian sensors and models are already tracking these indicators and their compounding effects, and the data are readily available for use or independent analysis. Appendix A provides a list of many such resources.

Organizationally, the responsibility for tracking and predicting these events should be more than just an additional duty for the meteorologists. Rather, the intelligence, operations, plans, and logistics sections within the AFRICOM organizations should extensively utilize this information.

While this paper focused on using remote sensing and predictive modeling to forecast rangeland failures and their regional impacts on pastoral societies, many of the same tools can and should be utilized for broader applications in Africa. Regional droughts and desertification

will also affect farmlands and threaten the water supplies of densely populated urban areas. Global climate change is anticipated to increase the frequency and severity of weather events, and rising sea levels and storm surges are projected to inundate lands currently occupied by 12 percent of the urban population of sub-Saharan Africa, massively affecting numerous countries.⁴⁹

To maintain situational awareness of on-going crises, it is critical for AFRICOM to recognize the implications of these indicators. However, using forecasting tools to identify developing problem areas will provide the greatest benefits. With this knowledge, AFRICOM is better positioned to work with partner organizations and nations to proactively prepare for instability before it develops, and potentially assist in preventing its occurrence.



Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

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- ¹ (Morrison, et al. 2008, 28)
 - ² (United States Africa Command n.d.)
 - ³ (Ward 2011)
 - ⁴ (Launchbaugh and Strand n.d.)
 - ⁵ (Nori and Davies 2007, 7)
 - ⁶ (Swift 1988, 2)
 - ⁷ (Brooks 2006, 2)
 - ⁸ (Barrow, et al. 2007, 1)
 - ⁹ (World Initiative for Sustainable Pastoralism 2008)
 - ¹⁰ (Kirkbride and Grahn 2008, 9)
 - ¹¹ (Kirkbride and Grahn 2008, 17)
 - ¹² (Niamir 1991, 1)
 - ¹³ (Nassef, Anderson and Hesse 2009, v)
 - ¹⁴ (Meier and Bond 2005, 2)
 - ¹⁵ (Conflict Early Warning and Response Mechanism 2011)
 - ¹⁶ (Webersik 2008, 13)
 - ¹⁷ (IRIN 2009)
 - ¹⁸ (US Agency for International Development 2007)
 - ¹⁹ (Internal Displacement Monitoring Center 2009, 29)
 - ²⁰ (National Weather Service 2006, 1)
 - ²¹ (Holechek, Pieper and Herbel 1998, 505)
 - ²² (Wylie, et al. 1983, 3)
 - ²³ (Hoerling, Hurrell and Eischeid 2005, 5)
 - ²⁴ (US Geological Survey 2010)
 - ²⁵ (US Agency for International Development 2010)
 - ²⁶ (US Agency for International Development 2010)
 - ²⁷ (NOAA National Weather Service Climate Prediction Center 2002)
 - ²⁸ (US Agency for International Development 2011)
 - ²⁹ (Climate Prediction Center 2010)
 - ³⁰ (Climate Prediction Center 2010)
 - ³¹ (Turner, et al. 2009, 19)
 - ³² (UNEP/GRID-Arendal 2002)
 - ³³ (Saha and Coauthors 2010, 1047)
 - ³⁴ (Thornton, et al. 2006, 3)
 - ³⁵ (Thornton, et al. 2006, 53)
 - ³⁶ (Thornton, et al. 2006, 53)
 - ³⁷ (Archer and Smeins 1991, 114)
 - ³⁸ (Holechek, Pieper and Herbel 1998, 496)
 - ³⁹ (Natural Resources Conservation Service n.d.)
 - ⁴⁰ (Planetary Skin Institute 2010)
 - ⁴¹ (Economist 2010)
 - ⁴² (United Nations Convention to Combat Desertification 2008)
 - ⁴³ (Eswaran, Reich and Beinroth 1998)
 - ⁴⁴ (P. F. Reich, S. T. Numbem, et al. 2001)
 - ⁴⁵ (Satellite Imaging Corporation 2009)
 - ⁴⁶ (P. F. Reich, R. A. Numbem, et al. 2001)
 - ⁴⁷ (P. F. Reich, S. T. Numbem, et al. 2001)
 - ⁴⁸ (Ibanez, Valderrama and Puigdefabregas 2008, 180)
 - ⁴⁹ (Dasgupta, et al. 2009, 16)

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Appendix A: Sources for Monitoring Indicators of African Rangeland Failure

USAID Famine Early Warning Systems Network

<http://www.fews.net/Pages/default.aspx>

NOAA National Weather Service Climate Prediction Center - Africa

<http://www.cpc.ncep.noaa.gov/products/fews/africa/>

Food and Agriculture Organization of the United Nations - FENIX portal

<http://www.foodsec.org/workstation/en/>

SERVIR - Africa

http://www.servir.net/africa/index.php?option=com_frontpage&Itemid=1

USGS FEWS NET Data Portal

<http://earlywarning.usgs.gov/fews/>

Conflict Early Warning and Response Network (CEWARN)

<http://cewarn.org/>

African Drought Risk and Development Network

<http://www.droughtnet.org/>

ALERTS - Automated Land change Evaluation, Reporting, and Tracking System project

<http://ourplanetaryskin.org/ps/is/land-change/#>